fd_IID-toolbox

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This Matlab toolbox provides a framework for frequency-specific quantification of the information shared between a target and two source time series (even multivariate). The interaction information decomposition is provided in the frequency domain and related to the time domain through the block-coherence estimator. The decomposition can be computed directly from the estimation of Power Spectral Density matrix through parametric and non-parametric approaches.

The framework is illustrated in simulations of linearly interacting stochastic processes, showing how it allows to retrieve amounts of information shared by the processes within specific frequency bands which are otherwise not detectable by time-domain information measures, as well as coupling features which are not detectable by spectral measures [1]. The performance of different parametric and non-parametric estimators are compared in simulative setting with a four-variate VAR process of interacting processes with a pre defined coupling structure [2]. Its application is also illustrated on three different datasets:

1. Electroencephalographic signals recorded from 109 healthy subjects performing a motor execution task [3]
2. Time series recorded from a unidirectionally-coupled ring of 32 electronic non-linear chaotic oscillator [4]
3. Three time series representative of the dynamic activity of three environmental variables: global land temperature, global temperature of the ocean and carbon dioxide volume [5]

[1]-Faes, Luca, et al. "Information Decomposition in the Frequency Domain: a New Framework to Study Cardiovascular and Cardiorespiratory Oscillations." bioRxiv (2020).

[2]-Antonacci, Yuri, et al. "Measuring High-Order Interactions in Rhythmic Processes: A Framework for the Spectral Information Decomposition of Multivariate Time Series.", IEEE Access (2021, sub)

[3]- https://physionet.org/content/eegmmidb/1.0.0/

[4]- Minati, Ludovico, et al. "Apparent remote synchronization of amplitudes: A demodulation and interference effect." Chaos: An Interdisciplinary Journal of Nonlinear Science 28.6 (2018): 063124.

[5]- E. system research laboratory, "Earth system research laboratory," https://www.esrl.noaa.gov/. NASA, "Nasa - goddard institute for space studies," https://data.giss.nasa.gov/

To get started, we recommend that you run and work through the demonstration scripts.

Demonstration scripts

Theoretical_Example - Shows the coexistence of synergy and redundancy in a VAR model of 4 interacting processes with a predefined coupling structure. Coupling between the two sources and the target is varied from 0 to 1 (Section III.A [2]).

Simulation_experiment - Reports the practical estimation of the interaction measures performed using parametric and non-parametric approaches on simulated multivariate time series generated as realization of a VAR(3) process. Ten realizations (to reduce computation time) of the processes were generated with a time-series length N=1000 (Section III.B [2]).

EEG_Analysis - Performs the analysis reported in the Section IV.A [2]. In particular, it is performed the interaction information decomposition in 109 healthy subjects performing a motor execution task (close the right fist / resting condition). The interaction information decomposition is performed through a parametric approach by selecting as target and source processes, three groups of EEG channels according to the physiology of the task. The estimated trends for the interaction information measures in the time and frequency domain, are averaged along the entire group of subjects and the two experimental conditions are compared through statistical test (Note that the analysis was reduced to one single subject due to the high computational time required for the entire procedure).

Chaotic_Oscillators_Analysis - Performs the study of high-order interactions between different triplets in a ring of 32 electronic oscillators. In particular, the interaction information decomposition in both time and frequency domain was performed by using a parametric approach as described in the method section.

The MatLab Script reproduces the results obtained in Section IV.B [2] in Figure 7. Note that the analysis was reduced to one single target due to high computation time required for the study of the entire ring.

Climate_Analysis - Performs all the analysis for the interaction information decomposition in a system composed by three different time series representative of three environmental variables: global land temperature, global temperature of the ocean and carbon dioxide volume. The time series referred to the period 1980-2019 with the analysis that was performed by using a non-parametric approach as described in the methods section [2].

Functions

- circularBuffer.m - converts regular MATLAB vector/matrix into circular vector/matrix. User specified index will be wrapped into valid index while accessing/mutating elements in circularBuffer object. All MATLAB vector/matrix operations are also valid for circularBuffer object. Anver Hisham (2021). https://www.mathworks.com/matlabcentral/fileexchange/52411-circularbuffer, MATLAB Central File Exchange. Retrieved June 28, 2021.

- tight_subplot.m - allows to adjust the spacing between the axes as well as the margins around the axes. Pekka Kumpulainen (2021). https://www.mathworks.com/matlabcentral/fileexchange/27991-tight_subplot-nh-nw-gap-marg_h-marg_w, MATLAB Central File Exchange. Retrieved June 28, 2021.

- MVARfilter.m - Filter a vector noise with a specified strictly causal MVAR model

- fdVAR.m - Frequency domain MVAR analysis. REFERENCE: Luca Faes and Giandomenico Nollo (2011). Multivariate Frequency Domain Analysis of Causal Interactions in Physiological Time Series, Biomedical Engineering, Trends in Electronics, Communications and Software, Anthony N. Laskovski (Ed.), ISBN: 978-953-307-475-7, InTech.

- idVAR.m - allows the identification of stricly causal MVAR model starting from the Time series and the estimated model order (part of fdPID toolbox http://www.lucafaes.net/fdPID.html)

- mos_idVAR.m - Allows the model order selection for identification of strictly causal MVAR model through Akaike Information Criterion or through Minimum Description Length
(part of fdPID toolbox http://www.lucafaes.net/fdPID.html)

- iispectral.m - allows the frequency domain source interaction measures as described in the main document (Section II.A-B). (part of fdPID toolbox http://www.lucafaes.net/fdPID.html)

- theoreticalVAR.m - Theoretical coefficients for simulated VAR processes. The use is demonstrated in the MatLab script, Theoretical_Example.m
- isstationary.m - Test weak sense stationarity of the data. Hristo Zhivomirov (2021). Signal Stationarity Estimation with Matlab (https://www.mathworks.com/matlabcentral/fileexchange/75118-signal-stationarity-estimation-with-matlab), MATLAB Central File Exchange. Retrieved June 28, 2021.
- surrogate_analysis.m - Computes the interaction information measure for surrogate time series
- demean.m - Temporal demean of time series data (part of MVGC toolbox http://www.sussex.ac.uk/sackler/mvgc/)
- whiteness.m - Durbin-Watson test for whiteness (no serial correlation) of VAR residuals (part of MVGC toolbox http://www.sussex.ac.uk/sackler/mvgc/)
- surriaafft2.m - function to generate IAAFFT surrogates as described in the Section II.D
- lab_read_edf.m - read eeg data in EDF+ format. fhz (2021). Read / Write EDF+ -Files (https://www.mathworks.com/matlabcentral/fileexchange/36530-read-write-edf-files), MATLAB Central File Exchange. Retrieved June 29, 2021.

Datasets description

- top_row.mat includes the signals produced by the 32 electronic oscillators measured over time.
- ClimateData.mat - Climatological time series analyzed in [2]
- S001 - includes the EEG signals recorded during motor execution task as described in [2].

Contacts

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